GR 99 P 8082

Abstract

Device for detecting polarization mode dispersion

Device for detecting polarization mode dispersion of an
optical data signal (OS), which has at least one EXOR
gate (EXj; j = 1 ... n) together with an averaging
device (LPj; j = 1 ... n) for measuring at least one
value (AKFj; j = 1 ... n) of the autocorrelation
function of a baseband signal (BB) distorted by
polarization mode dispersion.

Figure 1

FORM PTO-1390 (Modified) (REV 11-2000)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 112740-387

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
10/019526

INTERNATIONAL APPLICATION NO. PCT/DE00/01175	INTERNATIONAL FILING DATE 14 April 2000	PRIORITY DATE CLAIMED 28 June 1999

TITLE OF INVENTION
DEVICE FOR DETETING POLARIZATION MODE DISPERSION

APPLICANT(S) FOR DO/EO/US
Reinhold Noe

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.

4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).

5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).

6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).

7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☒ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.

8. ☒ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).

10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).

12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.

14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

15. ☒ A **FIRST** preliminary amendment.

16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.

17. ☒ A substitute specification.

18. ☐ A change of power of attorney and/or address letter.

19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.

20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).

21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).

22. ☒ Certificate of Mailing by Express Mail

23. ☐ Other items or information:

PCTUS1/REV03

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/019526	INTERNATIONAL APPLICATION NO. PCT/DE00/01175	ATTORNEY'S DOCKET NUMBER 112740-387

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1040.00

☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $890.00

☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO $740.00

☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) $710.00

☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00

ENTER APPROPRIATE BASIC FEE AMOUNT = $890.00

Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)). $0.00

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
Total claims	15 - 20 =	0	x $18.00	$0.00
Independent claims	1 - 3 =	0	x $84.00	$0.00
Multiple Dependent Claims (check if applicable).		☐		$0.00

TOTAL OF ABOVE CALCULATIONS = $890.00

☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2. $0.00

SUBTOTAL = $890.00

Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). + $0.00

TOTAL NATIONAL FEE = $890.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). ☐ $0.00

TOTAL FEES ENCLOSED = $890.00

Amount to be: refunded $
charged $

a. ☒ A check in the amount of ___$890.00___ to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. ___02-1818___ A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING: Information on this form may become public. Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

William E. Vaughan (Reg. No. 39,056)
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Chicago, Illinois 60690-1135

SIGNATURE

William E. Vaughan
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39,056
REGISTRATION NUMBER

December 27, 2001
DATE

BOX PCT

IN THE UNITED STATES ELECTED/DESIGNATED OFFICE

OF THE UNITED STATES PATENT AND TRADEMARK OFFICE

UNDER THE PATENT COOPERATION TREATY-CHAPTER II

5

PRELIMINARY AMENDMENT

APPLICANTS:	Reinhold Noe	DOCKET NO.:	112740-387
SERIAL NO:		GROUP ART UNIT:	
FILED:		EXAMINER:	
INTERNATIONAL APPLICATION NO::		PCT/DE00/01175	
INTERNATIONAL FILING DATE		14 April 2000	
INVENTION:		DEVICE FOR DETECTING POLARIZATION MODE DISPERSION	

Assistant Commissioner for Patents,
Washington, D.C. 20231

10

Sir:

Please amend the above-identified International Application before entry

into the National stage before the U.S. Patent and Trademark Office under 35

U.S.C. §371 as follows:

15 **In the Specification:**

Please replace the Specification of the present application, including the

Abstract, with the following Substitute Specification:

SPECIFICATION

TITLE OF THE INVENTION

20   DEVICE FOR DETECTING POLARIZATION MODE DISPERSION

BACKGROUND OF THE INVENTION

Long optical waveguide transmission links are used in optical transmission

technology. Production dictates that the optical waveguides are not completely

isotropic, but rather weakly birefringent. The long transmission link results in

25   frequency-dependent polarization transformation, called polarization mode

dispersion or polarization dispersion, abbreviated to PMD. Through the change in

421601/D/2 CRN102_

the polarization of the optical signal as a function of the optical frequency and, associated therewith, different frequency-dependent delays, this PMD leads to the widening of transmitted pulses. As such, at the receiving end, the identifiability of the pulses is reduced and, as a result, the transmitted data rate is limited. The term

5 "principal states of polarization", referred to as PSP below, designates those two states of polarization which are orthogonal to one another and to a first approximation do not change when the optical frequency changes. In polarization-maintaining optical waveguides, the principal states of polarization coincide with the principal axes; in other words, are horizontal and vertical. In general, however,

10 the principal states of polarization are arbitrary orthogonal pairs of elliptic states of polarization. The principal states of polarization have different group delays, whose difference is referred to as "differential group delay", DGD below. If an optical signal is transmitted with one principal state of polarization, then, to a first-order approximation, no pulse widening takes place. If it is transmitted with a

15 polarization which, in the case of splitting according to the two principal states of polarization, corresponds to power components that are identical there, maximum pulse widening occurs because two pulses of identical strength, with delay differences equal to DGD, are superposed. If the principal states of polarization change as a function of the optical frequency, then it is the case, however, that,

20 when a principal state of polarization which corresponds to a specific frequency is used on the input side, the output state of polarization will nevertheless change as a function of the frequency, but actually only in a higher order than the first order. This is referred to as higher-order PMD. Higher-order PMD generally occurs, although first-order PMD is predominant due to its effects and, therefore, must be

25 compensated preferentially. This is aggravated by the fact that the transmission response of the link, and hence the PMD too, changes as a result of temperature change or mechanical stress. Therefore, use is made of adaptive PMD compensators which are inserted in the transmission path. To drive these compensators, PMD distortions must be detected in the optical receiver. The

30 compensator can then be set optimally using a gradient algorithm, for example.

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In Electronic Letters, February 17, 1994, Volume 30, no. 4, pages 348 to 349, use is made of a bandpass filter for filtering a data signal whose PMD is to be detected. A power detector at the filter output supplies a signal which is higher, the smaller the PMD distortions are. In Electron. Lett. 34(1998) 23, pages 2258 to 2259, use is made of a combination of a number of bandpass filters with downstream power detectors, in which case, instead of individual signals, it is also possible to use a linear combination of the signals. By using bandpass filters having different center frequencies, it becomes possible, at the same time, to detect even relatively large PMD distortions which exceed, e.g., a bit duration of the signal. However, bandpass filters are poorly suited to monolithic integration; for example, in Si or SiGe. Moreover, unavoidable group delay distortions in the bandpass filters have the result that optimal PMD detection and hence equalization is not possible.

In Proceedings OEC 94, 14e-12, pages 258 to 259, Makuhari Trade Fair, Japan 1994, a different method is used, in which the power of the differential signal between decision-circuit output and decision-circuit input is evaluated. Incorrect decisions may occur, however, particularly in the event of severe PMD distortions in which the DGD exceeds the bit duration, so that the signal obtained in such cases is an unsuitable criterion for the presence of PMD distortions.

An object of the present invention, therefore, is to specify a reliable detector even for relatively large values of the differential group delay which can be integrated in a simple manner and, unlike bandpass filters, is not subject to intrinsic distortions through group delay distortions.

SUMMARY OF THE INVENTION

According to the present invention, use is made of EXCLUSIVE-OR gates (EXOR) or multipliers, which are used to determine essential parts of the autocorrelation function of the baseband signal present in the electrical part of an optical receiver. A particular advantage of the present invention is that EXOR gates can be monolithically integrated in a simple manner.

With EXOR gates which are separated by delay lines, the autocorrelation function values are produced for different time delays.

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In an advantageous exemplary embodiment, two delay lines that are to be traversed in opposite directions are used, which can be implemented in a particularly space-saving manner and, moreover, at least approximately compensate the line losses.

5   Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a device according to the present invention for PMD
10   detection, supplemented by PMD compensator and further assemblies.

Figure 2 shows a poor and a good sampled autocorrelation function.

Figure 3 shows a further exemplary embodiment of a device for PMD detection.

Figure 4 shows a variant of delay lines.
15   Figure 5 shows a further variant of a delay line.

Figure 6 shows a regenerator connected to a regulator.

DETAILED DESCRIPTION OF THE FIGURES

Figure 1 shows a system for optical PMD compensation having an optical input IN and an optical output OUT. An optical wave OS, coming from the input
20   IN, traverses firstly an adjustable optical PMD compensator PMDC and then a power divider LT. One output of the power divider forms the optical output OUT of the system and the other drives a photodiode PD. After electrical amplification in amplifier V, the baseband signal BB is fed to an electrical power divider LTE.

The outputs of the electrical power divider are fed to two tapped delay lines LZ1,
25   LZ2. The ends of the delay lines are provided with terminating resistors R1, R2 in accordance with the characteristic impedance. A tap A1j (j = 1 ... n) of the line LZ1 is respectively fed to one input and a tap A2j (j = 1 ... n) of the line LZ2 is respectively fed to the other input of an EXOR gate EXj (j = 1 ... n).

Instead of EXOR gates, any other multiplier circuits are also suitable.
30   Gilbert multipliers are particularly suitable as EXOR gates/multipliers. A suitable circuit, in this case with field-effect transistors, is presented, for example, in

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Electronics Letters, August 15, 1991, Volume 27, no. 17, pages 1529 to 1532, to be precise in Fig. 3 therein.

The taps are arranged according to a rising index j on one of the lines (LZ1) and according to a falling index j on the other line (LZ2). The result of this is that

5 the delay difference between the signals at the inputs of an EXOR gate EXj changes monotonically with rising index j. If the line lengths between all the adjacent taps of a respective line are equal, then equidistant delay differences which change monotonically in accordance with index j are produced. Low-pass filters LPj (j = 1 ... n) are respectively connected to the outputs of the EXOR gates EXj.

10 Instead of low-pass filters, other circuits which can be used for averaging, such as integrators, for example, which integrate over a defined time duration, are also suitable. These are also referred to as "Integrate-and-Dump" circuits. The output signals of the low-pass filters specify the values of the autocorrelation function of the electrical signal BB which are measured for different delay differences.

15 In order to compensate the losses at the taps A1j, A2j, to suppress multiple reflections on the delay lines LZ1, LZ2 and to obtain a longer signal delay for given dimensions, buffer amplifiers V1j, V2j (j = 1 ... n) may be inserted into the delay lines LZ1, LZ2. However, they are not absolutely necessary.

Since balanced circuitry with differential inputs and push-pull outputs

20 affords numerous advantages, it is favorable to use it here, too. By way of example, amplifier V, power divider LTE, delay lines LZ1, LZ2, buffer amplifiers V1k, V2k, taps A1j, A2j, terminating resistors R1, R2, EXOR gates EXj and low-pass filters LPj may be of balanced design. The last-mentioned literature reference describes how this is done for, e.g., an EXOR gate.

25 EXOR gates EXj and at least parts of the delay lines LZ1, LZ2 including taps A1j, A2j and terminating resistors R1, R2 and, if present, buffer amplifiers V1k, V2k form an autocorrelation unit AKE. The latter may, for example, also include the remainder of the delay lines LZ1, LZ2, the electrical power divider LTE and the amplifier V. An autocorrelation unit AKE1 can be monolithically

30 integrated in a space-saving manner on a semiconductor chip; e.g., in SiGe, GaAs or InP.

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In practice, the taps give rise to losses on the delay lines LZ1, LZ2. However, since the input signals of all the EXOR gates traverse, in total, the same number of taps, i.e. upon addition of the traversed taps on line LZ1 and the traversed taps on LZ2, and, given a suitable design, also traverse line portions that are of the same length, in total, the product of the attenuation factors which these input signals experience is constant. This is true even in the absence of buffer amplifiers V1k, V2k. This advantageously has the result that the output signals of the different EXOR gates EXj correspond, with at least approximately the same proportionality factor, proportionally to the value of the autocorrelation function which corresponds to the respective delay.

In the exemplary embodiment of Figure 1, the signal delays between the outputs of the electrical power divider LTE and the taps A11 and A21 respectively, shall be identical. In this way, the value AKF1 of the autocorrelation function of the baseband signal BB for delay zero is produced at the output of the low-pass filter LP1. Between adjacent tap points A1k and A1(k+1) (k = 1 ... n-1) the signal delays shall be identical and have the value DT1. Between respectively adjacent tap points A2(k+1) and A2k (k = 1 ... n-1), the signal delays shall be identical and have the value DT2. Since the delay lines LZ1, LZ2 are traversed in opposite directions in the region of the EXOR gates, the value AKF2, AKF3, ... AKFn of the autocorrelation function of the baseband signal BB for delays DT, 2*DT, ..., (n-1)*DT, where DT = DT1+DT2, is respectively produced at the outputs of the remaining low-pass filters LP2 ... LPn. In order to minimize the chip area, it is advantageous to choose DT1 = DT2. It is furthermore favorable to choose DT to be equal to or shorter than a symbol duration T of the baseband signal BB. In the case of the binary signals usually used, a symbol duration T is equal to a bit duration. Since the autocorrelation function of a real signal has even symmetry, it is possible to dispense with the measurement of the values of the autocorrelation function with opposite delays. The maximum delay (n-1)*DT should, if possible, be at least equal to the sum of a differential group delay, caused by PMD, of the optical transmission link and the differential group delay generated by the PMD compensator PMDC.

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The outputs of the low-pass filters LBj are fed to a regulator R. An autocorrelation function AKF sampled by values AKF1 ... AKFn is thus present here. If PMD is present and is not equalized, the value AKF1 is often smaller than the maximum possible value and the values AKF2 ... AKFn differ from zero even

5   when they correspond to delays DT ... (n-1)*DT greater than a symbol duration T of the baseband signal. Such a poor autocorrelation function AKFBAD is shown by Figure 2. Only half of the autocorrelation function is shown since, after all, the autocorrelation function is symmetrical, so that measurement of the other half is unnecessary.

10   The regulator R adjusts the control signals SPMDC of the PMD compensator PMDC in such a way that the autocorrelation function is at least approximately equal to the autocorrelation function of the undistorted baseband signal. In the case of NRZ signals, this is a triangular pulse centered about delay zero, which pulse reaches the value zero for a delay of one bit duration T and

15   remains there for longer delays. Such a good autocorrelation function AKFGOOD is also shown by Figure 2. In this case, the value AKF1 is maximal and the values AKF2 ... AKFn are at least approximately equal to zero when the delays DT ... (n-1)*DT are at least as long as a symbol duration T of the baseband signal. This applies to the values 2*DT ... (n-1)*DT in Figure 2. PMD is ideally equalized in

20   this case. An ideally equalized optical signal therefore appears at the optical output OUT.

The optical power divider LT can also be omitted, so that the PMD compensator PMDC is directly connected to the photodiode PD on the output side. In this case, the electrical power divider LTE, as shown in Figure 1, should have a

25   further electrical output LTEOR. An electrical data regenerator (often called 3R regenerator) REG is connected to the electrical output LTEOR. A regenerated data signal which at least approximately has no bit errors through PMD is available at the output OD of the regenerator.

Figure 3 shows a further exemplary embodiment of the device for PMD

30   detection. Only the autocorrelation unit AKE of Figure 1 and a power divider LTE are shown here. In Figure 3, the signal flow directions of the delay lines LZ1, LZ2

along the EXOR gates are not opposite, as in Figure 1, but rather unidirectional. This can be seen also from the opposite positioning of the terminating resistor R2 and the opposite orientation of the buffer amplifiers V2j. As in Figure 1, buffer amplifiers are not absolutely necessary, or may be provided, e.g., only at some

5   points.

In Figure 3, time delay DT1 shall be defined in the same way as in Figure 1. Between respectively adjacent tap points A2k and A2(k+1) (k = 1 ... n-1) of Figure 3, the signal delays shall be identical and have the value DT3. The delay differences between the inputs of successive correlators are therefore 0, DT, 2*DT ... (n-1)*DT

10   where DT in this case has the value DT = DT1 - DT3. In order to obtain different DT1, DT3, detour lines Um (m = 2 ... n) are provided.

Instead of tapped delay lines LZ1, LZ2, it is also possible to use a number of delay lines LZ1j, LZ2j (j = 1 ... n) of different lengths. To that end, the power divider LTE must have a corresponding number of outputs. A suitable exemplary

15   embodiment where n=4 is sketched in Figure 4. The delay lines LZ1j, LZ2j end at those points A1j, A2j which are connected to the EXOR gate inputs and were the tap points in Figures 1 and 2. The delay differences between the point pairs (A11, A21), (A12, A22), (A13, A23), (A14, A24) are 0, DT, 2*DT and 3*DT, respectively, where DT = DT1 + DT2.

20   Figure 5 illustrates part of an exemplary embodiment with only one delay line LZ1. The points A1j, which are connected to one EXOR gate input in each case, are strung along the delay line LZ1. The points A2j, which are connected to the other EXOR gate input in each case, all coincide and are identical to the point A11. Delay differences 0, DT, 2*DT ... (n-1)*DT between the EXOR gate inputs

25   are obtained in this way.

In order to achieve an optimally low bit error rate, it is expedient for a measure of this bit error rate to be made available to the regulator R. This is possible in a simple manner if an electrical regenerator REG is provided. It may, therefore, be expedient to provide a regenerator REG even in cases where power

30   divider LT and optical output OUT of the equalized optical signal are present. Figure 6 illustrates the regenerator REG. Clock recovery is generally necessary but

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is not illustrated here for reasons of clarity. The regenerated data signal DS appears at the output OD, which is also the output of a D flip-flop DFF, to which the baseband signal BB is fed on the input side. The baseband signal is likewise fed to a second decision circuit (D flip-flop) DFF2. In this exemplary embodiment, the threshold of the decision circuit can be adjusted via a setting device EG to such an extent that the decision circuit already yields a data auxiliary signal DH affected by errors when the first decision circuit DFF still outputs an essentially error-free data signal DS. The output signals are compared with one another in an EXCLUSIVE-OR gate EXOR, and the error signal FS thus obtained is likewise fed to the regulator R for controlling the PMD compensator PMDC. A measure of how good the signal quality is with regard to a bit error rate that can be achieved is continuously developed by shifting the threshold of the second decision circuit via a setting device EG, which is controlled by the regulator R via a control signal ST2. The lower the error rate of the data auxiliary signal when the threshold is shifted from the optimum, the better the signal quality. Roughly, a maximum value of the autocorrelation function AKF1 for delay zero and zero values of the autocorrelation function for delays which are longer than a symbol duration T will also produce a minimum bit error rate. By contrast, a more accurate assessment which leads to a lower bit error rate of the decision circuit DFF is produced when the error signal FS is used. Since deviations of the data auxiliary signal DH from the data signal DS occur stochastically, however, a relatively long measurement or averaging time of the error signal FS is necessary in order to obtain a particularly good signal/noise ratio and, hence, optimal compensation. The additional information obtained with the aid of the second decision circuit is used to adaptively modify the regulating algorithm of the regulator R, which performs the setting of the PMD compensator PMDC with the aid of autocorrelation function measured values AKF1, AKF2, ... AKFn. By way of example, a slightly negative value AKF3 might be more favorable than the value zero. This adaptive form of operation appears to be particularly favorable for making manufacturing tolerances, temperature fluctuations, occurrence of nonlinear effects, etc., tolerable. The major advantage of these embodiments is that, through the measured values of the autocorrelation

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function, rapid PMD compensation is already possible and sufficient time is available for the fine setting and the setting of the transfer function of the filter.

However, it is also possible to use only an error signal FS, particularly in cases where fast setting of the PMD compensator PMDC is not important. In this case, electrical power divider LTE and autocorrelation unit AKE and low-pass filters LPj may be omitted.

Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

ABSTRACT OF THE DISCLOSURE

Device for detecting polarization mode dispersion of an optical data signal, which has at least one EXOR gate together with an averaging device for measuring at least one value of the autocorrelation function of a baseband signal distorted by

5   polarization mode dispersion.

In the claims:

On page 12, cancel line 1, and substitute the following left-hand justified heading therefor:

5   CLAIMS

Please cancel claims 1-13, without prejudice, and substitute the following claims therefor:

14.   A device for detecting polarization mode dispersion of an optical data signal by evaluating an electrical baseband signal, comprising:

10   at least one multiplier which calculates a value of an autocorrelation function of the baseband signal by multiplication of a value of the baseband signal by a delayable value of the baseband signal; and

an averaging device for averaging the calculated value of the autocorrelation function.

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15.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:

a delay line with taps, wherein taps with different delays are respectively connected to inputs of the at least one multiplier.

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16.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein two delay lines are provided through which, in a region in which the two delay lines exhibit a mutual assignment via the inputs of the at least one multiplier, the baseband signal runs in opposite directions

25   such that the delays occurring between adjacent multipliers are added to form a delay difference between the adjacent multipliers.

17.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein two delay lines are provided which, in

30   a region in which the two delay lines exhibit an assignment via the inputs of the at least one multiplier, are traversed in a same direction such that the delays occurring

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between adjacent multipliers are subtracted from one another to form a delay difference between the adjacent multipliers.

18.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:
a plurality of delay lines of different lengths to whose ends inputs of multipliers are connected.

19.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, further comprising:
a detour line provided in one of the delay lines.

20.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, further comprising:
a buffer amplifier in one of the delay lines.

21.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein delays that occur are equidistant with a constant delay difference.

22.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein a delay difference is at least approximately equal to a symbol duration of the baseband signal.

23.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:
a regulator for controlling a PMD compensator.

24.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 23, wherein the regulator at least approximately maximizes a non-delayed value of the autocorrelation function and adjusts values

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of the autocorrelation function that are delayed by at least one symbol duration at least approximately to the value zero.

25.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:

a measuring arrangement for measuring a bit error rate in the event of one of an intentionally impaired reception signal and a changed threshold value of a second decision stage, an error signal of the measuring arrangement controlling a PMD compensator via a regulator.

26.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 25, wherein the regulator is used additionally for adaptively setting the values of the autocorrelation function that are sought.

27.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, wherein the multiplier is an EXOR gate.

28.   A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, where the multiplier is a Gilbert multiplier.

REMARKS

The present amendment makes editorial changes and corrects typographical errors in the specification, which includes the Abstract, in order to conform the specification to the requirements of United States Patent Practice. No new matter is added thereby. Attached hereto is a marked-up version of the changes made to the specification by the present amendment. The attached page is captioned "**Version With Markings To Show Changes Made**".

In addition, the present amendment cancels original claims 1-13 in favor of new claims 14-28. Claims 14-28 have been presented solely because the revisions by red-lining and underlining which would have been necessary in claims 1-13 in order to present those claims in accordance with preferred United States Patent Practice would have been too extensive, and thus would have been too burdensome. The present amendment is intended for clarification purposes only and not for substantial reasons related to patentability pursuant to 35 USC §§101, 102, 103 or 112. Indeed, the cancellation of claims 1-13 does not constitute an intent on the part of the Applicants to surrender any of the subject matter of claims 1-13.

Early consideration on the merits is respectfully requested.

Respectfully submitted,
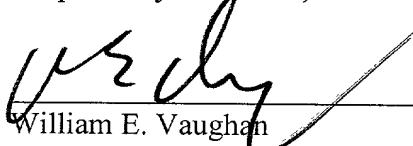
(Reg. No. 39,056)

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~~Description~~

SPECIFICATION

~~Device for detecting polarization mode dispersion~~

5   TITLE OF THE INVENTION

DEVICE FOR DETECTING POLARIZATION MODE DISPERSION

~~The invention relates to a device for detecting polarization mode dispersion~~
~~of an optical data signal in accordance with the preamble of patent claim 1.~~

BACKGROUND OF THE INVENTION

10   Long optical waveguide transmission links are used in optical transmission
technology. Production dictates that the optical waveguides are not completely
isotropic, but rather weakly birefringent. The long transmission link results in
frequency-dependent polarization transformation-, called polarization mode
dispersion or polarization dispersion, abbreviated to PMD. Through the change in

15   the polarization of the optical signal as a function of the optical frequency and-,
associated therewith-, different frequency-dependent delays, this PMD leads to the
widening of transmitted pulses~~, which means that~~. As such, at the receiving end,
the identifiability of ~~said~~ the pulses is reduced and, as a result, the transmitted data
rate is limited. The term "principal states of polarization", referred to as PSP

20   below, designates those two states of polarization which are orthogonal to one
another and to a first approximation do not change when the optical frequency
changes. In polarization-maintaining optical waveguides, the principal states of
polarization coincide with the principal axes,; in other words, are horizontal and
vertical. In general, however, the principal states of polarization are arbitrary

25   orthogonal pairs of elliptic states of polarization. The principal states of
polarization have different group delays, whose difference is referred to as
"differential group delay", DGD below. If an optical signal is transmitted with one
principal state of polarization, then, to a first-order approximation, no pulse
widening takes place. If it is transmitted with a polarization which, in the case of

30   splitting according to the two principal states of polarization, corresponds to power
components that are identical there, maximum pulse widening occurs because two

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pulses of identical strength, with delay differences equal to DGD, are superposed. If the principal states of polarization change as a function of the optical frequency, then it is the case, however, that, when a principal state of polarization which corresponds to a specific frequency is used on the input side, the output state of

5   polarization will nevertheless change as a function of the frequency, but actually only in a higher order than the first order. This is referred to as higher-order PMD. Higher-order PMD generally occurs, although first-order PMD is predominant due to its effects and must, therefore, must be compensated preferentially. This is aggravated by the fact that the transmission response of the link, and hence the

10   PMD too, changes as a result of temperature change or mechanical stress. Therefore, use is made of adaptive PMD compensators which are inserted in the transmission path. To drive these compensators, PMD distortions must be detected in the optical receiver. The compensator can then be set optimally using a gradient algorithm, for example.

15   In Electronic Letters, February 17, 1994, Volume 30, no. 4, pages 348 to 349, use is made of a bandpass filter for filtering a data signal whose PMD is to be detected. A power detector at the filter output supplies a signal which is higher, the smaller the PMD distortions are. In Electron. Lett. 34(1998) 23, pages 2258 to 2259, use is made of a combination of a plurality number of bandpass filters with

20   downstream power detectors, in which case, instead of individual signals, it is also possible to use a linear combination of the signals. By using bandpass filters having different center frequencies, it becomes possible, at the same time, to detect even relatively large PMD distortions which exceed, e.g., a bit duration of the signal. However, bandpass filters are poorly suited to monolithic integration, for

25   example, in Si or SiGe. Moreover, unavoidable group delay distortions in the bandpass filters have the result that optimal PMD detection and hence equalization is not possible.

          In Proceedings OEC 94, 14e-12, pages 258 to 259, Makuhari Trade Fair, Japan 1994, a different method is used, in which the power of the differential signal

30   between decision-circuit output and decision-circuit input is evaluated. Incorrect decisions may occur, however, particularly in the event of severe PMD distortions

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in which the DGD exceeds the bit duration, so that the signal obtained in such cases is an unsuitable criterion for the presence of PMD distortions.

~~The~~ An object of the <u>present</u> invention, therefore, is to specify a reliable detector even for relatively large values of the differential group delay which can be

5   integrated in a simple manner and, unlike bandpass filters, is not subject to intrinsic distortions through group delay distortions.

~~The object is achieved by means of a device for detecting polarization mode dispersion in accorance with claim 1.~~

SUMMARY OF THE INVENTION

10   ~~Advantageous developments of the invention are specified in the subclaims.~~

~~According to the~~ According to the present invention, use is made of EXCLUSIVE-OR gates (EXOR) or multipliers, which are used to determine essential parts of the autocorrelation function of the baseband signal present in the electrical part of an optical receiver. ~~The~~ A particular advantage of the <u>present</u>

15   invention is that EXOR gates can be monolithically integrated in a simple manner.

With EXOR gates which are separated by delay lines, the autocorrelation function values are produced for different time delays.

In an advantageous exemplary embodiment, two delay lines that are to be traversed in opposite directions are used, which can be implemented in a

20   particularly space-saving manner and, moreover, at least approximately compensate the line losses.

~~Exemplary embodiments of the invention will be described with reference to figures.~~ Additional features and advantages of the present invention are described <u>in, and will be apparent from, the following Detailed Description of the Invention</u>

25   <u>and the Figures.</u>

~~In the figures:~~ BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a device according to the <u>present</u> invention for PMD detection, supplemented by PMD compensator and further assemblies~~;~~.

Figure 2 shows a poor and a good sampled autocorrelation function~~;~~.

30   Figure 3 shows a further exemplary embodiment of a device for PMD detection~~;~~.

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Figure 4 shows a variant of delay lines,.

Figure 5 shows a further variant of a delay line, and.

Figure 6 shows a regenerator connected to a regulator.

DETAILED DESCRIPTION OF THE FIGURES

5   Figure 1 shows a system for optical PMD compensation. It has having an
optical input IN and an optical output OUT. An optical wave OS, coming from the
input IN, traverses firstly an adjustable optical PMD compensator PMDC and then
a power divider LT. One output of the power divider forms the optical output OUT
of the system and the other drives a photodiode PD. After electrical amplification
10   in amplifier V, the baseband signal BB is fed to an electrical power divider LTE.

The outputs of the electrical power divider are fed to two tapped delay lines
LZ1, LZ2. The ends of the delay lines are provided with terminating resistors R1, R2 in
accordance with the characteristic impedance. A tap $A1j$ ($j = 1 \dots n$) of the line LZ1 is
respectively fed to one input and a tap $A2j$ ($j = 1 \dots n$) of the line LZ2 is respectively fed
15   to the other input of an EXOR gate EXj ($j = 1 \dots n$).

Instead of EXOR gates, any other multiplier circuits are also suitable.
Gilbert multipliers are particularly suitable as EXOR gates/multipliers. A suitable
circuit, in this case with field-effect transistors, is presented, for example, in
Electronics Letters, August 15, 1991, Volume 27, no. 17, pages 1529 to 1532, to be
20   precise in Fig. 3 therein.

The taps are arranged according to a rising index j on one of the lines (LZ1)
and according to a falling index j on the other line (LZ2). The result of this is that
the delay difference between the signals at the inputs of an EXOR gate EXj changes
monotonically with rising index j. If the line lengths between all the adjacent taps
25   of a respective line are equal, then equidistant delay differences which change
monotonically in accordance with index j are produced. Low-pass filters LPj
($j = 1 \dots n$) are respectively connected to the outputs of the EXOR gates EXj.
Instead of low-pass filters, other circuits which can be used for averaging, such as
integrators, for example, which integrate over a defined time duration, are also
30   suitable. These are also referred to as "Integrate-and-Dump" circuits. The output

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signals of the low-pass filters specify the values of the autocorrelation function of the electrical signal BB which are measured for different delay differences.

In order to compensate the losses at the taps A1j, A2j, to suppress multiple reflections on the delay lines LZ1, LZ2 and to obtain a longer signal delay for given dimensions, buffer amplifiers V1j, V2j (j = 1 ... n) may be inserted into the delay lines LZ1, LZ2. However, they are not absolutely necessary.

Since balanced circuitry with differential inputs and push-pull outputs affords numerous advantages, it is favorable to use it here, too. By way of example, amplifier V, power divider LTE, delay lines LZ1, LZ2, buffer amplifiers V1k, V2k, taps A1j, A2j, terminating resistors R1, R2, EXOR gates EXj and low-pass filters LPj may be of balanced design. The last-mentioned literature reference describes how this is done ~~for,~~ e.g., for an EXOR gate.

EXOR gates EXj and at least parts of the delay lines LZ1, LZ2 including taps A1j, A2j and terminating resistors R1, R2 and, if present, buffer amplifiers V1k, V2k form an autocorrelation unit AKE. The latter may, for example, also ~~comprise~~ include the remainder of the delay lines LZ1, LZ2, the electrical power divider LTE and the amplifier V. An autocorrelation unit AKE1 can be monolithically integrated in a space-saving manner on a semiconductor chip~~,~~, e.g., in SiGe, GaAs or InP.

In practice, the taps give rise to losses on the delay lines LZ1, LZ2. However, since the input signals of all the EXOR gates traverse, in total, the same number of taps, i.e. upon addition of the traversed taps on line LZ1 and the traversed taps on LZ2, and, given a suitable design, also traverse line portions that are of the same length, in total, the product of the attenuation factors which these input signals experience is constant. This is true even in the absence of buffer amplifiers V1k, V2k. This advantageously has the result that the output signals of the different EXOR gates EXj correspond, with at least approximately the same proportionality factor, proportionally to the value of the autocorrelation function which corresponds to the respective delay.

In the exemplary embodiment of Figure 1, the signal delays between the outputs of the electrical power divider LTE and the taps A11 and A21 respectively,

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shall be identical. In this way, the value AKF1 of the autocorrelation function of the baseband signal BB for delay zero is produced at the output of the low-pass filter LP1. Between adjacent tap points A1k and A1(k+1) (k = 1 ... n-1) the signal delays shall be identical and have the value DT1. Between respectively adjacent tap points A2(k+1) and A2k (k = 1 ... n-1), the signal delays shall be identical and have the value DT2. Since the delay lines LZ1, LZ2 are traversed in opposite directions in the region of the EXOR gates, the value AKF2, AKF3, ... AKFn of the autocorrelation function of the baseband signal BB for delays DT, 2*DT, ..., (n-1)*DT, where DT = DT1+DT2, is respectively produced at the outputs of the remaining low-pass filters LP2 ... LPn. In order to minimize the chip area, it is advantageous to choose DT1 = DT2. It is furthermore favorable to choose DT to be equal to or shorter than a symbol duration T of the baseband signal BB. In the case of the binary signals usually used, a symbol duration T is equal to a bit duration. Since the autocorrelation function of a real signal has even symmetry, it is possible to dispense with the measurement of the values of the autocorrelation function with opposite delays. The maximum delay (n-1)*DT should, if possible, be at least equal to the sum of a differential group delay-, caused by PMD-, of the optical transmission link and the differential group delay generated by the PMD compensator PMDC.

The outputs of the low-pass filters LBj are fed to a regulator R. An autocorrelation function AKF sampled by values AKF1 ... AKFn is thus present here. If PMD is present and is not equalized, the value AKF1 is often smaller than the maximum possible value and the values AKF2 ... AKFn differ from zero even when they correspond to delays DT ... (n-1)*DT greater than a symbol duration T of the baseband signal. Such a poor autocorrelation function AKFBAD is shown by Figure 2. Only half of the autocorrelation function is shown since, after all, s̶a̶i̶d̶ the autocorrelation function is symmetrical, so that measurement of the other half is unnecessary.

The regulator R adjusts the control signals SPMDC of the PMD compensator PMDC in such a way that the autocorrelation function is at least approximately equal to the autocorrelation function of the undistorted baseband

signal. In the case of NRZ signals, this is a triangular pulse centered about delay zero, which pulse reaches the value zero for a delay of one bit duration T and remains there for longer delays. Such a good autocorrelation function AKFGOOD is also shown by Figure 2. In this case, the value AKF1 is maximal and the values

5   AKF2 ... AKFn are at least approximately equal to zero when the delays DT ... (n-1)*DT are at least as long as a symbol duration T of the baseband signal. This applies to the values 2*DT ... (n-1)*DT in Figure 2. PMD is ideally equalized in this case. An ideally equalized optical signal therefore appears at the optical output OUT.

10   The optical power divider LT can also be omitted, so that the PMD compensator PMDC is directly connected to the photodiode PD on the output side. In this case, the electrical power divider LTE, as shown in Figure 1, should have a further electrical output LTEOR. An electrical data regenerator (often called 3R regenerator) REG is connected to said the electrical output LTEOR. A regenerated

15   data signal which at least approximately has no bit errors through PMD is available at the output OD of said the regenerator.

Figure 3 shows a further exemplary embodiment of the device for PMD detection. Only the autocorrelation unit AKE of Figure 1 and a power divider LTE are shown here. In Figure 3, the signal flow directions of the delay lines LZ1, LZ2

20   along the EXOR gates are not opposite, as in Figure 1, but rather unidirectional. This can also be seen also from the opposite positioning of the terminating resistor R2 and the opposite orientation of the buffer amplifiers V2j. As in Figure 1, buffer amplifiers are not absolutely necessary, or may be provided, e.g., only at some points.

25   In Figure 3, time delay DT1 shall be defined in the same way as in Figure 1. Between respectively adjacent tap points A2k and A2(k+1) (k = 1 ... n-1) of Figure 3, the signal delays shall be identical and have the value DT3. The delay differences between the inputs of successive correlators are therefore 0, DT, 2*DT ... (n-1)*DT where DT in this case has the value DT = DT1 - DT3. In order to

30   obtain different DT1, DT3, detour lines Um (m = 2 ... n) are provided.

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Instead of tapped delay lines LZ1, LZ2, it is also possible to use a ~~plurality~~ number of delay lines LZ1j, LZ2j (j = 1 ... n) of different lengths. To that end, the power divider LTE must have a corresponding number of outputs. A suitable exemplary embodiment where n=4 is sketched in Figure 4. The delay lines LZ1j,

5   LZ2j end at those points A1j, A2j which are connected to the EXOR gate inputs and were the tap points in Figures 1 and 2. The delay differences between the point pairs (A11, A21), (A12, A22), (A13, A23), (A14, A24) are 0, DT, 2*DT and 3*DT, respectively, where DT = DT1 + DT2.

Figure 5 illustrates part of an exemplary embodiment with only one delay

10   line LZ1. The points A1j, which are connected to one EXOR gate input in each case, are strung along the delay line LZ1. The points A2j, which are connected to the other EXOR gate input in each case, all coincide and are identical to the point A11. Delay differences 0, DT, 2*DT ... (n-1)*DT between the EXOR gate inputs are obtained in this way.

15   In order to achieve an optimally low bit error rate, it is expedient for a measure of this bit error rate to be made available to the regulator R. This is possible in a simple manner if an electrical regenerator REG is provided. It may, therefore, be expedient to provide a regenerator REG even in cases where power divider LT and optical output OUT of the equalized optical signal are present.

20   Figure 6 illustrates the regenerator REG. Clock recovery is generally necessary but is not illustrated here for reasons of clarity. The regenerated data signal DS appears at the output OD, which is also the output of a D flip-flop DFF, to which the baseband signal BB is fed on the input side. The baseband signal is likewise fed to a second decision circuit (D flip-flop) DFF2.

25   In this exemplary embodiment, the threshold of the decision circuit can be adjusted via a setting device EG to such an extent that ~~said~~ the decision circuit already yields a data auxiliary signal DH affected by errors when the first decision circuit DFF still outputs an essentially error-free data signal DS. The output signals are compared with one another in an EXCLUSIVE-OR gate EXOR, and the error

30   signal FS thus obtained is likewise fed to the regulator R for controlling the PMD compensator PMDC. A measure of how good the signal quality is with regard to a

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bit error rate that can be achieved is continuously developed by shifting the threshold of the second decision circuit ~~by means of~~ via a setting device EG, which is controlled by the regulator R via a control signal ST2. The lower the error rate of the data auxiliary signal when the threshold is shifted from the optimum, the better

5   the signal quality. Roughly, a maximum value of the autocorrelation function AKF1 for delay zero and zero values of the autocorrelation function for delays which are longer than a symbol duration T will also produce a minimum bit error rate. By contrast, a more accurate assessment which leads to a lower bit error rate of the decision circuit DFF is produced when the error signal FS is used. Since

10   deviations of the data auxiliary signal DH from the data signal DS occur stochastically, however, a relatively long measurement or averaging time of the error signal FS is necessary in order to obtain a particularly good signal/noise ratio and, hence, optimal compensation. The additional information obtained with the aid of the second decision circuit is used to adaptively modify the regulating

15   algorithm of the regulator R, which performs the setting of the PMD compensator PMDC with the aid of autocorrelation function measured values AKF1, AKF2, ... AKFn. By way of example, a slightly negative value AKF3 might be more favorable than the value zero. This adaptive form of operation appears to be particularly favorable for making manufacturing tolerances, temperature

20   fluctuations, occurrence of nonlinear effects, etc., tolerable. The major advantage of these embodiments is that, through the measured values of the autocorrelation function, rapid PMD compensation is already possible and sufficient time is available for the fine setting and the setting of the transfer function of the filter.

       However, it is also possible to use only an error signal FS, particularly in

25   cases where fast setting of the PMD compensator PMDC is not important. In this case, electrical power divider LTE and autocorrelation unit AKE and low-pass filters LPj may be omitted.

       Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made

30   thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

ABSTRACT OF THE DISCLOSURE ~~Abstract~~

~~Device for detecting polarization mode dispersion~~

Device for detecting polarization mode dispersion of an optical data signal~~(OS)~~, which has at least one EXOR gate ~~(EXj; j = 1 ... n)~~ together with an averaging device ~~(LPj; j = 1 ... n)~~ for measuring at least one value ~~(AKFj; j = 1 ... n)~~ of the autocorrelation function of a baseband signal ~~(BB)~~ distorted by polarization mode dispersion.

~~Figure 1~~

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5/p&b - 1 -

Description

Device for detecting polarization mode dispersion

5   The invention relates to a device for detecting
polarization mode dispersion of an optical data signal
in accordance with the preamble of patent claim 1.

Long optical waveguide transmission links are used in
10   optical transmission technology. Production dictates
that the optical waveguides are not completely
isotropic, but rather weakly birefringent. The long
transmission link results in frequency-dependent
polarization transformation - called polarization mode
15   dispersion or polarization dispersion, abbreviated to
PMD. Through the change in the polarization of the
optical signal as a function of the optical frequency
and - associated therewith - different frequency-
dependent delays, this PMD leads to the widening of
20   transmitted pulses, which means that, at the receiving
end, the identifiability of said pulses is reduced and,
as a result, the transmitted data rate is limited. The
term "principal states of polarization", referred to as
PSP below, designates those two states of polarization
25   which are orthogonal to one another and to a first
approximation do not change when the optical frequency
changes.   In   polarization-maintaining   optical
waveguides, the principal states of polarization
coincide with the principal axes, in other words are
30   horizontal and vertical. In general, however, the
principal states of polarization are arbitrary
orthogonal pairs of elliptic states of polarization.
The principal states of polarization have different
group delays, whose difference is referred to as
35   "differential group delay", DGD below. If an optical
signal is transmitted with one principal state of
polarization, then, to a first-order approximation, no
pulse widening takes place. If it is transmitted with a

polarization which, in the case of splitting according
to the two principal states of polarization,
corresponds to power components that are identical
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pulse widening occurs because two pulses of identical
strength, with delay differences equal to DGD, are
superposed. If the principal states of polarization
change as a function of the optical frequency, then it
5   is the case, however, that, when a principal state of
polarization which corresponds to a specific frequency
is used on the input side, the output state of
polarization will nevertheless change as a function of
the frequency, but actually only in a higher order than
10   the first order. This is referred to as higher-order
PMD. Higher-order PMD generally occurs, although first-
order PMD is predominant due to its effects and must
therefore be compensated preferentially. This is
aggravated by the fact that the transmission response
15   of the link, and hence the PMD too, changes as a result
of temperature change or mechanical stress. Therefore,
use is made of adaptive PMD compensators which are
inserted in the transmission path. To drive these
compensators, PMD distortions must be detected in the
20   optical receiver. The compensator can then be set
optimally using a gradient algorithm, for example.

In Electronic Letters, February 17, 1994, Volume 30,
no. 4, pages 348 to 349, use is made of a bandpass
25   filter for filtering a data signal whose PMD is to be
detected. A power detector at the filter output
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2258 to 2259, use is made of a combination of a
30   plurality of bandpass filters with downstream power
detectors, in which case, instead of individual
signals, it is also possible to use a linear
combination of the signals. By using bandpass filters
having different center frequencies, it becomes
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large PMD distortions which exceed e.g. a bit duration
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suited to monolithic integration, for example

in Si or SiGe. Moreover, unavoidable group delay distortions in the bandpass filters have the result that optimal PMD detection and hence equalization is not possible.

In Proceedings OEC 94, 14e-12, pages 258 to 259, Makuhari Trade Fair, Japan 1994, a different method is used, in which the power of the differential signal between decision-circuit output and decision-circuit input is evaluated. Incorrect decisions may occur, however, particularly in the event of severe PMD distortions in which the DGD exceeds the bit duration, so that the signal obtained in such cases is an unsuitable criterion for the presence of PMD distortions.

The object of the invention is to specify a reliable detector even for relatively large values of the differential group delay which can be integrated in a simple manner and, unlike bandpass filters, is not subject to intrinsic distortions through group delay distortions.

The object is achieved by means of a device for detecting polarization mode dispersion in accorance with claim 1.

Advantageous developments of the invention are specified in the subclaims.

According to the invention, use is made of EXCLUSIVE-OR gates (EXOR) or multipliers, which are used to determine essential parts of the autocorrelation function of the baseband signal present in the electrical part of an optical receiver. The particular advantage of the invention is that EXOR gates can be monolithically integrated in a simple manner.

With EXOR gates which are separated by delay lines, the autocorrelation function values are produced for different time delays.

In an advantageous exemplary embodiment, two delay
lines that are to be traversed in opposite directions
are

used, which can be implemented in a particularly space-
saving manner and, moreover, at least approximately
compensate the line losses.

5   Exemplary   embodiments   of   the   invention   will   be
described with reference to figures.

In the figures:

10   Figure 1   shows a device according to the invention for
                PMD   detection,   supplemented   by   PMD
                compensator and further assemblies,
     Figure 2   shows   a   poor   and   a   good   sampled
                autocorrelation function,
15   Figure 3   shows   a   further   exemplary   embodiment   of   a
                device for PMD detection,
     Figure 4   shows a variant of delay lines,
     Figure 5   shows a further variant of a delay line, and
     Figure 6   shows a regenerator connected to a regulator.
20
     Figure 1 shows a system for optical PMD compensation.
     It has an optical input IN and an optical output OUT.
     An optical wave OS, coming from the input IN, traverses
     firstly an adjustable optical PMD compensator PMDC and
25   then   a   power   divider   LT.   One   output   of   the   power
     divider forms the optical output OUT of the system and
     the   other   drives   a   photodiode   PD.   After   electrical
     amplification in amplifier V, the baseband signal BB is
     fed to an electrical power divider LTE.
30
     The outputs of the electrical power divider are fed to two
     tapped delay lines LZ1, LZ2. The ends of the delay lines
     are   provided   with   terminating   resistors   R1,   R2   in
     accordance with the characteristic impedance. A tap A1j
35   (j = 1 ... n) of the line LZ1 is respectively fed to one
     input   and   a   tap   A2j   (j = 1 ... n)   of   the   line   LZ2   is
     respectively fed to the other input of an EXOR gate EXj
     (j = 1 ... n).

Instead of EXOR gates, any other multiplier circuits
are also suitable. Gilbert multipliers are particularly
suitable as EXOR gates/multipliers. A suitable circuit,
in this case with field-effect transistors, is
5   presented for example in Electronics Letters, August
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The taps are arranged according to a rising index j on
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they are not absolutely necessary.

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Since balanced circuitry with differential inputs and
push-pull outputs affords numerous advantages, it is
favorable to use it here, too. By way of example,

amplifier V, power divider LTE, delay lines LZ1, LZ2,
buffer amplifiers V1k, V2k, taps A1j, A2j,

terminating resistors R1, R2, EXOR gates EXj and low-pass filters LPj may be of balanced design. The last-mentioned literature reference describes how this is done for e.g. an EXOR gate.

5

EXOR gates EXj and at least parts of the delay lines LZ1, LZ2 including taps A1j, A2j and terminating resistors R1, R2 and, if present, buffer amplifiers V1k, V2k form an autocorrelation unit AKE. The latter may, for example, also comprise the remainder of the delay lines LZ1, LZ2, the electrical power divider LTE and the amplifier V. An autocorrelation unit AKE1 can be monolithically integrated in a space-saving manner on a semiconductor chip, e.g. in SiGe, GaAs or InP.

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In practice, the taps give rise to losses on the delay lines LZ1, LZ2. However, since the input signals of all the EXOR gates traverse, in total, the same number of taps, i.e. upon addition of the traversed taps on line LZ1 and the traversed taps on LZ2, and, given a suitable design, also traverse line portions that are of the same length, in total, the product of the attenuation factors which these input signals experience is constant. This is true even in the absence of buffer amplifiers V1k, V2k. This advantageously has the result that the output signals of the different EXOR gates EXj correspond, with at least approximately the same proportionality factor, proportionally to the value of the autocorrelation function which corresponds to the respective delay.

In the exemplary embodiment of Figure 1 the signal delays between the outputs of the electrical power divider LTE and the taps A11 and A21 respectively, shall be identical. In this way, the value AKF1 of the autocorrelation function of the baseband signal BB for delay zero is produced at the output of the low-pass

filter LP1. Between adjacent tap points A1k and A1(k+1)
(k = 1 ... n-1) the signal delays shall be identical

and have the value DT1. Between respectively adjacent tap points A2(k+1) and A2k (k = 1 ... n-1), the signal delays shall be identical and have the value DT2. Since the delay lines LZ1, LZ2 are traversed in opposite

5   directions in the region of the EXOR gates, the value AKF2, AKF3, ... AKFn of the autocorrelation function of the baseband signal BB for delays DT, 2*DT, ..., (n-1)*DT, where DT = DT1+DT2, is respectively produced at the outputs of the remaining low-pass filters LP2

10   ... LPn. In order to minimize the chip area, it is advantageous to choose DT1 = DT2. It is furthermore favorable to choose DT to be equal to or shorter than a symbol duration T of the baseband signal BB. In the case of the binary signals usually used, a symbol

15   duration T is equal to a bit duration. Since the autocorrelation function of a real signal has even symmetry, it is possible to dispense with the measurement of the values of the autocorrelation function with opposite delays. The maximum delay

20   (n-1)*DT should, if possible, be at least equal to the sum of a differential group delay - caused by PMD - of the optical transmission link and the differential group delay generated by the PMD compensator PMDC.

25   The outputs of the low-pass filters LBj are fed to a regulator R. An autocorrelation function AKF sampled by values AKF1 ... AKFn is thus present here. If PMD is present and is not equalized, the value AKF1 is often smaller than the maximum possible value and the values

30   AKF2 ... AKFn differ from zero even when they correspond to delays DT ... (n-1)*DT greater than a symbol duration T of the baseband signal. Such a poor autocorrelation function AKFBAD is shown by **Figure 2**. Only half of the autocorrelation function is shown

35   since, after all, said autocorrelation function is symmetrical, so that measurement of the other half is unnecessary.

The regulator R adjusts the control signals SPMDC of
the PMD compensator PMDC in such a way that the
autocorrelation function

is at least approximately equal to the autocorrelation function of the undistorted baseband signal. In the case of NRZ signals, this is a triangular pulse centered about delay zero, which pulse reaches the value zero for a delay of one bit duration T and remains there for longer delays. Such a good autocorrelation function AKFGOOD is also shown by Figure 2. In this case, the value AKF1 is maximal and the values AKF2 ... AKFn are at least approximately equal to zero when the delays DT ... (n-1)*DT are at least as long as a symbol duration T of the baseband signal. This applies to the values 2*DT ... (n-1)*DT in Figure 2. PMD is ideally equalized in this case. An ideally equalized optical signal therefore appears at the optical output OUT.

The optical power divider LT can also be omitted, so that the PMD compensator PMDC is directly connected to the photodiode PD on the output side. In this case, the electrical power divider LTE, as shown in Figure 1, should have a further electrical output LTEOR. An electrical data regenerator (often called 3R regenerator) REG is connected to said electrical output LTEOR. A regenerated data signal which at least approximately has no bit errors through PMD is available at the output OD of said regenerator.

Figure 3 shows a further exemplary embodiment of the device for PMD detection. Only the autocorrelation unit AKE of Figure 1 and a power divider LTE are shown here. In Figure 3, the signal flow directions of the delay lines LZ1, LZ2 along the EXOR gates are not opposite, as in Figure 1, but rather unidirectional. This can also be seen from the opposite positioning of the terminating resistor R2 and the opposite orientation of the buffer amplifiers V2j. As in Figure 1, buffer amplifiers are not absolutely necessary, or may be provided e.g. only at some points.

In Figure 3, time delay DT1 shall be defined in the same way as in Figure 1. Between respectively adjacent tap points A2k and A2(k+1) (k = 1 ... n-1) of Figure 3, the signal delays shall be identical and have the value DT3.

5 The delay differences between the inputs of successive correlators are therefore 0, DT, 2*DT ... (n-1)*DT where DT in this case has the value DT = DT1 - DT3. In order to obtain different DT1, DT3, detour lines   Um (m = 2 ... n) are provided.

10

Instead of tapped delay lines LZ1, LZ2, it is also possible to use a plurality of delay lines LZ1j, LZ2j (j = 1 ... n) of different lengths. To that end, the power divider LTE must have a corresponding number of

15 outputs. A suitable exemplary embodiment where n=4 is sketched in **Figure 4**. The delay lines LZ1j, LZ2j end at those points A1j, A2j which are connected to the EXOR gate inputs and were the tap points in Figures 1 and 2. The delay differences between the point pairs (A11,

20 A21), (A12, A22), (A13, A23), (A14, A24) are 0, DT, 2*DT and 3*DT, respectively, where DT = DT1 + DT2.

Figure 5 illustrates part of an exemplary embodiment with only one delay line LZ1. The points A1j, which are

25 connected to one EXOR gate input in each case, are strung along the delay line LZ1. The points A2j, which are connected to the other EXOR gate input in each case, all coincide and are identical to the point A11. Delay differences 0, DT, 2*DT ... (n-1)*DT between the

30 EXOR gate inputs are obtained in this way.

In order to achieve an optimally low bit error rate, it is expedient for a measure of this bit error rate to be made available to the regulator R. This is possible in

35 a simple manner if an electrical regenerator REG is provided. It may therefore be expedient to provide a regenerator REG even in cases where power divider LT

and optical output OUT of the equalized optical signal
are present. **Figure 6**

illustrates the regenerator REG. Clock recovery is generally necessary but is not illustrated here for reasons of clarity. The regenerated data signal DS appears at the output OD, which is also the output of a
5 D flip-flop DFF, to which the baseband signal BB is fed on the input side. The baseband signal is likewise fed to a second decision circuit (D flip-flop) DFF2.

In this exemplary embodiment, the threshold of the decision circuit can be adjusted via a setting device
10 EG to such an extent that said decision circuit already yields a data auxiliary signal DH affected by errors when the first decision circuit DFF still outputs an essentially error-free data signal DS. The output signals are compared with one another in an EXCLUSIVE-
15 OR gate EXOR, and the error signal FS thus obtained is likewise fed to the regulator R for controlling the PMD compensator PMDC. A measure of how good the signal quality is with regard to a bit error rate that can be achieved is continuously developed by shifting the
20 threshold of the second decision circuit by means of a setting device EG, which is controlled by the regulator R via a control signal ST2. The lower the error rate of the data auxiliary signal when the threshold is shifted from the optimum, the better the signal quality.
25 Roughly, a maximum value of the autocorrelation function AKF1 for delay zero and zero values of the autocorrelation function for delays which are longer than a symbol duration T will also produce a minimum bit error rate. By contrast, a more accurate assessment
30 which leads to a lower bit error rate of the decision circuit DFF is produced when the error signal FS is used. Since deviations of the data auxiliary signal DH from the data signal DS occur stochastically, however, a relatively long measurement or averaging time of the
35 error signal FS is necessary in order to obtain a particularly good signal/noise ratio and hence optimal compensation. The additional information obtained with the aid of the second decision circuit is used to

adaptively modify the regulating algorithm of the
regulator R, which performs the setting of the PMD
compensator PMDC with the aid of autocorrelation

function measured values AKF1, AKF2, ... AKFn. By way
of example, a slightly negative value AKF3 might be
more favorable than the value zero. This adaptive form
of operation appears to be particularly favorable for
5 making   manufacturing   tolerances,   temperature
fluctuations, occurrence of nonlinear effects etc.
tolerable. The major advantage of these embodiments is
that,   through   the   measured   values   of   the
autocorrelation function, rapid PMD compensation is
10 already possible and sufficient time is available for
the fine setting and the setting of the transfer
function of the filter.

However, it is also possible to use only an error
15 signal FS, particularly in cases where fast setting of
the PMD compensator PMDC is not important. In this
case, electrical power divider LTE and autocorrelation
unit AKE and low-pass filters LPj may be omitted.

Patent claims

1.   A   device   for   detecting   polarization   mode
     dispersion   of   an   optical   data   signal   (OS)   by
     evaluating   an   electrical   baseband   signal   (BB),
     characterized
     in that at least one multiplier (EXj; j = 1 ... n)
     is   provided,   which   calculates   a   value   (AKFj;
     j = 1 ... n) of the autocorrelation function (AKF)
     of the baseband signal (BB) by multiplication of a
     value   of   the   baseband   signal   (BB)   by   a   delayable
     value   of   the   baseband   signal   and   subsequent
     averaging   in   an   averaging   device   (LPj;
     j = 1 ... n).

2.   The device as claimed in claim 1,
     characterized
     in that a delay line (LZ1, LZ2) with taps (A1j,
     A2j; j = 1 ... n) is provided, in that taps (A1j
     and A2j) with different delays (0, DT, 2*DT, ...
     (n-1,*DT) are respectively connected to the inputs
     of a multiplier (EXj).

3.   The device as claimed in claim 2,
     characterized
     in that two delay lines (LZ1, LZ2) are provided,
     through which, in the region in which they exhibit
     a mutual assignment via the inputs of multipliers
     (EXj), said baseband signal (BB) runs in opposite
     directions,   so   that   the   delays   (DT1,   DT2)
     occurring between adjacent multipliers (EXk and
     EX(k+1); k = 1 ... n-1) are added to form a delay·
     difference   (DT = DT1 + DT2)   between   said
     multipliers.

4.   The device as claimed in claim 2,
     characterized

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in that two delay lines (LZ1, LZ2) are provided,
which, in the region in which they exhibit an
assignment via the inputs of multipliers

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(EXj), are traversed in the same direction, so that the delays (DT1, DT3) occurring between adjacent multipliers (EXk and EX(k+1); k = 1 ... n-1) are subtracted from one another to form a delay difference (DT = DT1 - DT3) between said multipliers.

5. The device as claimed in claim 1,
characterized
in that a plurality of delay lines (LZ1j, LZ2j; j = 1 ... n) of different lengths are provided, to whose ends (A1j, A2j; j = 1 ... n) the inputs of multipliers (EXj) are connected.

6. The device as claimed in one of claims 2 to 5,
characterized
in that a detour line (Um; m = 2 ... n) or a buffer amplifier (V1j, V2j; j = 1 ... n) is provided in a delay line (LZ1, LZ2, LZ1j, LZ2j; j = 1 ... n).

7. The device as claimed in one of claims 2 to 6,
characterized
in that delays (0, DT, 2*DT, ... (n-1)*DT) that occur are equidistant with a constant delay difference (DT).

8. The device as claimed in one of claims 2 to 7,
characterized
in that a delay difference (DT) is at least approximately equal to a symbol duration (T) of the baseband signal (BB).

9. The device as claimed in one of the preceding claims,
characterized
in that provision is made of a regulator (R) for controlling a PMD compensator (PMDC).

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10. The device as claimed in claim 9,
    characterized
    in that the regulator (R) at least approximately
    maximizes a non-delayed value (AKF1) of the
5   autocorrelation function and adjusts values (AKF2,
    AKF3 ... AKFn) of the autocorrelation function
    that are delayed by at least one symbol duration
    (T) at least approximately to the value zero.

10 11. The device as claimed in one of the preceding
    claims,
    characterized
    in that provision is made of a measuring
    arrangement (EG; DFF2; EXOR) for measuring the bit
15 error rate in the event of an intentionally
    impaired reception signal or a changed threshold
    value of a second decision stage (DFF2), whose
    error signal (FS) controls a PMD compensator
    (PMDC) via a regulator (R).
20

12. The device as claimed in claim 11,
    characterized
    in that the regulator (R) is used additionally for
    adaptively setting the values of the
25 autocorrelation function (AKFj; j = 1 ... n) that
    are to be sought.

13. The device as claimed in one of the preceding
    claims,
30 characterized
    in that the multiplier (EXj) is an EXOR gate or a
   Gilbert multiplier

FIG 1
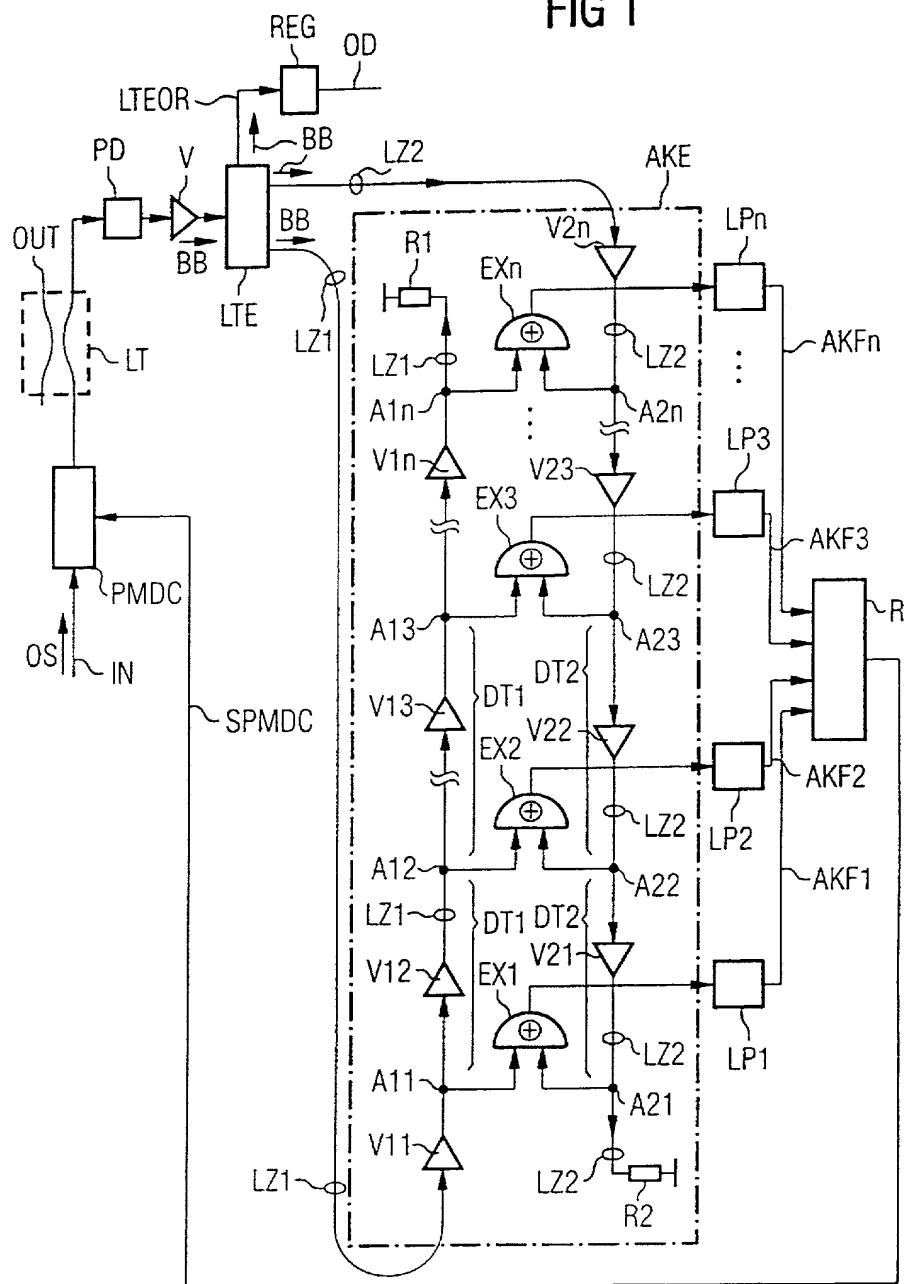
FIG 2
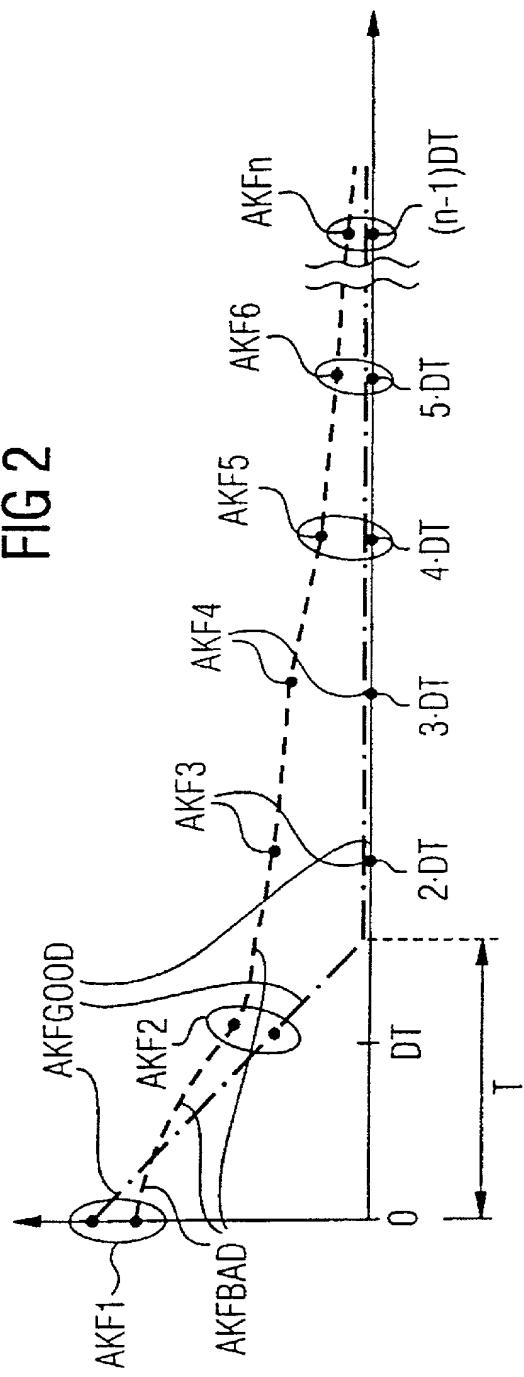
# FIG 3
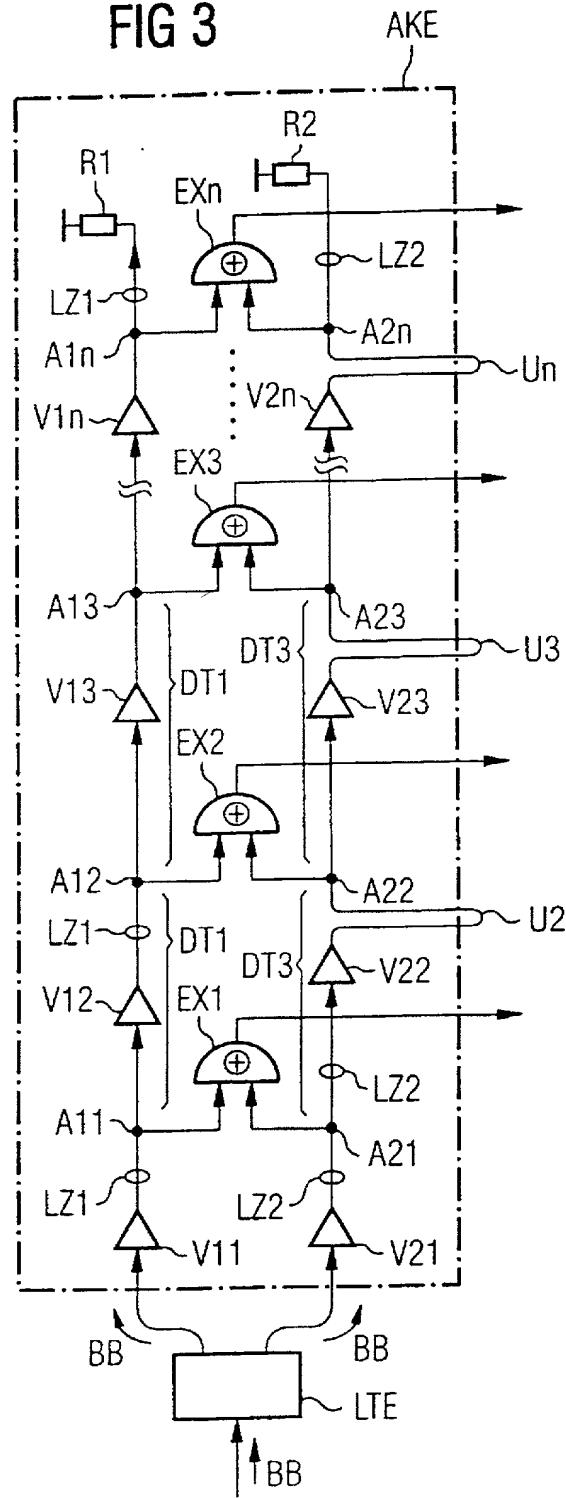
FIG 4
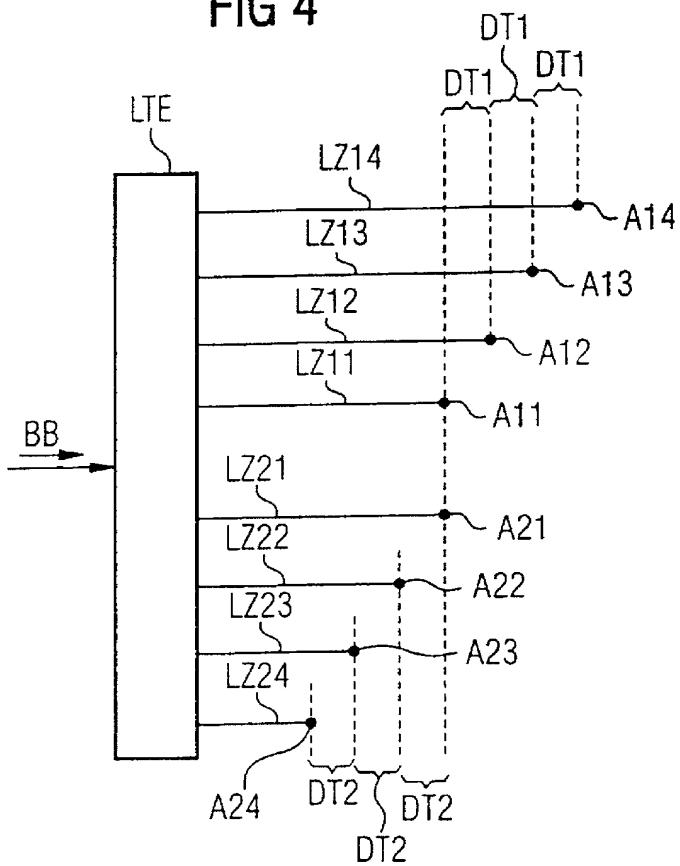
FIG 5
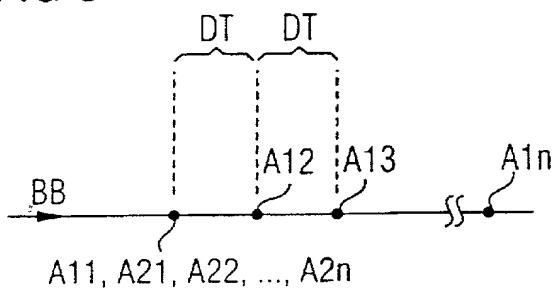
FIG 6
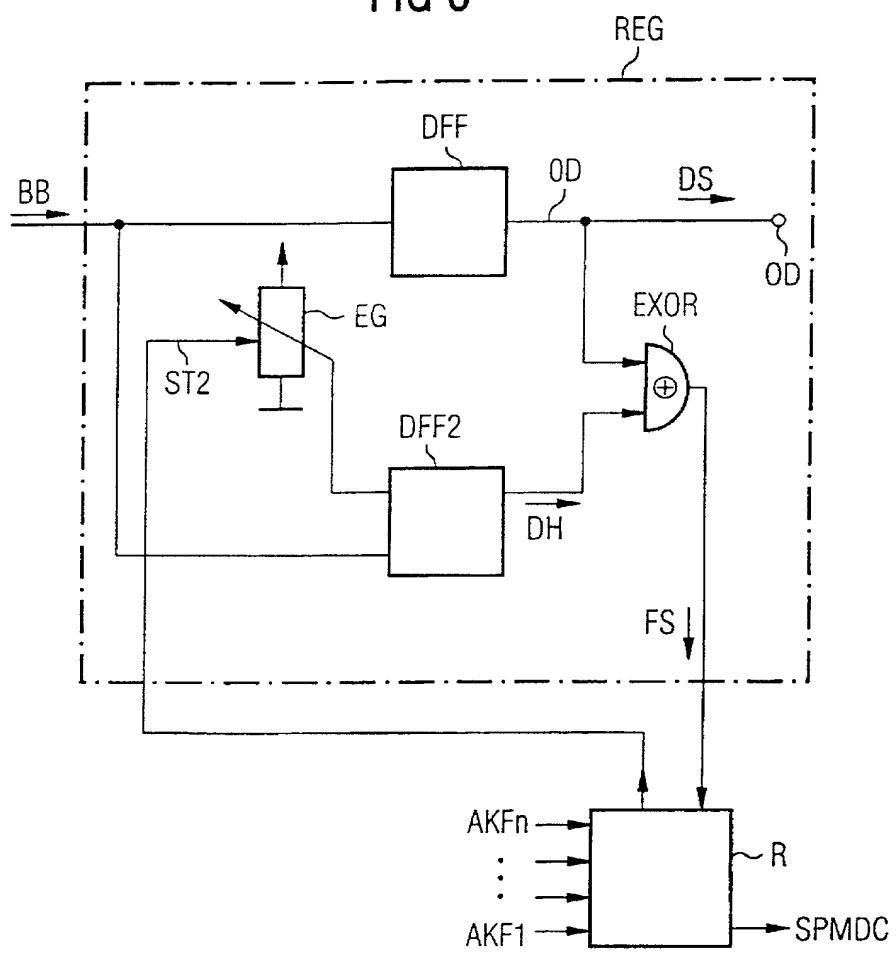
Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
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As a below named inventor, I hereby declare that:

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My residence, post office address and citizenship are as stated below next to my name,

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Einrichtung zur Detektion von Polarisationsmodendispersion

Device for detecting polarization mode dispersions

deren Beschreibung

the specification of which

(zutreffendes ankreuzen)
☐ hier beigefügt ist.
☒ am __14.04.2000__ als
PCT internationale Anmeldung
PCT Anmeldungsnummer _____PCT/DE00/01175
eingereicht wurde und am _____
abgeändert wurde (falls tatsächlich abgeändert).

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☐ is attached hereto.
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I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

Ich beanspruche hiermit ausländische Prioritätsvorteile gemäss Abschnitt 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 119 aller unten angegebenen Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde, und habe auch alle Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde nachstehend gekennzeichnet, die ein Anmeldedatum haben, das vor dem Anmeldedatum der Anmeldung liegt, für die Priorität beansprucht wird.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

IDNR: 2590 / V: 99-1.00 / B:Val

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Prior foreign appplications
Priorität beansprucht

<u>Priority Claimed</u>

<u>19929673.1</u>   <u>DE</u>   <u>28.06.1999</u>

(Number)   (Country)   (Day Month Year Filed)   ☒   ☐

(Nummer)   (Land)   (Tag Monat Jahr eingereicht)   Yes   No

                                                                                   Ja   Nein

(Number)   (Country)   (Day Month Year Filed)   ☐   ☐

(Nummer)   (Land)   (Tag Monat Jahr eingereicht)   Yes   No

                                                                                   Ja   Nein

(Number)   (Country)   (Day Month Year Filed)   ☐   ☐

(Nummer)   (Land)   (Tag Monat Jahr eingereicht)   Yes   No

                                                                                    Ja   Nein

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I hereby claim the benefit under Title 35. United States Code. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application and the national or PCT international filing date of this application.

<u>PCT/DE00/01175</u>   <u>14.04.2000</u>   <u>anhängig</u>   <u>pending</u>

(Application Serial No.)   (Filing Date D, M, Y)   (Status)   (Status)

(Anmeldeseriennummer)   (Anmeldedatum T, M, J) (patentiert, anhängig,   (patented, pending,

                                                               aufgegeben)   abandoned)

(Application Serial No.)   (Filing Date D,M,Y)   (Status)   (Status)

(Anmeldeseriennummer)   (Anmeldedatum T, M; J) (patentiert, anhängig,   (patented, pending,

                                                               aufgeben)   abandoned)

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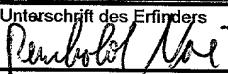
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Voller Name des einzigen oder ursprünglichen Erfinders:	Full name of sole or first inventor:
Prof. REINHOLD NOE	Prof. REINHOLD NOE
Unterschrift des Erfinders Datum 28.11.2001	Inventor's signature Date
Wohnsitz PADERBORN, DEUTSCHLAND	Residence PADERBORN, GERMANY
Staatsangehörigkeit AT	Citizenship AT
Postanschrift HELMERNER WEG 2	Post Office Address HELMERNER WEG 2
33100 PADERBORN	33100 PADERBORN
Voller Name des zweiten Miterfinders (falls zutreffend):	Full name of second joint inventor, if any:
Unterschrift des Erfinders Datum	Second Inventor's signature Date
Wohnsitz	Residence
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(Supply similar information and signature for third and subsequent joint inventors).

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